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A CLIMATIC DIGEST FOR GREATER TULSA

Robert A. Taft Sanitary Engineering Center
Cincinnati, Ohio

March 1958

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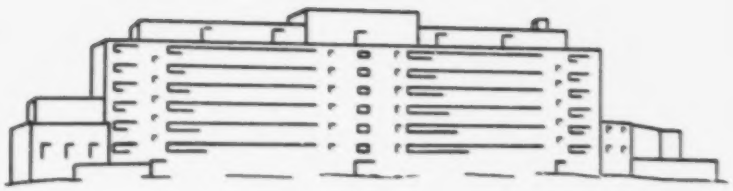

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U.S. DEPARTMENT OF HEALTH,
EDUCATION, AND WELFARE
Public Health Service

1958

A CLIMATIC DIGEST FOR GREATER TULSA

This report was prepared under a joint study agreement by the Public Health Service, the Weather Bureau, and the Tulsa Planning Commission, 1958-1959.

Edward W. Burt, USWB
Meteorology Section
Community Air Pollution Program

U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Bureau of State Services
Division of Sanitary Engineering Services

Robert A. Taft Sanitary Engineering Center
Cincinnati 26, Ohio
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CONTENTS

		Page
I.	INTRODUCTION	1
II.	BROAD SCALE TOPOGRAPHY AND CLIMATOLOGY	1
	A. TOPOGRAPHY	1
	B. CLIMATOLOGY	1
III.	TOPOGRAPHY AND CLIMATOLOGY OF THE GREATER TULSA AREA	3
	A. TOPOGRAPHY	3
	B. CLIMATOLOGY	4
	1. Winds	4
	2. Temperature and Relative Humidity	6
	3. Visibility	7
	4. Precipitation	8
	5. Sky Cover	9
IV.	SUMMARY AND CONCLUSIONS	10
V.	REFERENCES	11
	TABLES 1 and 2	13

A CLIMATIC DIGEST FOR GREATER TULSA

I. INTRODUCTION

This climatic summary has been prepared mainly from records of weather observations taken at the Tulsa Municipal Airport by the United States Weather Bureau. The monthly and annual climatological summaries regularly prepared by the Weather Bureau are not always applicable to air pollution problems; therefore, special tabulations were prepared from punch card listings of regular weather observations by the National Weather Records Center (3,5,7,8), and were heavily relied upon in preparing this report.

II. BROAD SCALE TOPOGRAPHY AND CLIMATOLOGY

A. TOPOGRAPHY

Oklahoma is situated in the southern part of the Great Plains. The ground elevations in this state decrease more or less gradually from about 4500 feet in the panhandle to about 350 feet in the southeast corner of the state. The easternmost main ridge of the Rocky Mountains (generally about 6000 to 10,000 feet) lies approximately 500 miles west, and the Gulf of Mexico approximately 500 miles south, of Tulsa.

The Ouachita Mountains of the extreme southeastern section of Oklahoma rise to about 2000 feet in places. They lie to the south-southeast and southeast of Tulsa at a distance of about 125 miles. The Boston Mountains of Arkansas lie about 100 miles east of Tulsa, and reach an elevation of 1700 feet or more.

B. CLIMATOLOGY

There are several basic features which determine the climatology of the southern Great Plains area: the warm-season quasi-stationary thermal low of the southwestern United States, the western extension of the semi-permanent North Atlantic anticyclone, the migratory cyclones which develop in the dynamic troughs just east of

the Rockies and in or near Oklahoma and Texas, and the cold anticyclones which move southward over this area.

The thermal low mentioned above is a warm weather phenomenon, and generally appears only on the surface and low-level pressure charts. A study of cyclone frequencies, which includes both migratory and stationary low-pressure areas, shows that low-pressure areas were centered in southern Arizona for approximately 20 percent of the days during the month of July, based on a 40-year period of record.(4) According to this study, there is no other area (defined as 5 degrees of latitude x 5 degrees of longitude) in the northern hemisphere in which this frequency is approached in any month of the year. The effect of the counterclockwise circulation around this warm-season thermal low and the clockwise circulation of the Atlantic anticyclone is to produce a persistent southerly wind flow in the southern Great Plains during the summer months.

Oklahoma is located approximately in the center of an area bounded on the south and north by latitudes 30 and 40 degrees north, and on the east and west by longitudes 90 and 105 degrees west. Table 1 was prepared from maps included in the above mentioned study, and shows the frequency of days with one or more cyclone centers (the majority, by far, being migratory) located within this area. The greatest number of days with cyclone centers in this region occurs during the spring (March through May), and the least from midsummer to midautumn (July through October). Cyclone frequency might be used as an indication of atmospheric ventilation over an area, since stronger winds, convergence, the resultant "lifting" of air to higher levels, and change of air masses are associated with cyclonic activity. These factors result in good atmospheric diffusion and the rapid transport of pollutants from the area.

There are no major orographic features in the United States or Canada to offer resistance to the southward advancement of air masses into the Mid-west. Thus, cool and cold air masses from Canada can readily move into the Great Plains area. The southeastern section of this region often experiences cloudy skies and light precipitation in winter while under the influence of these cool or cold,

dry air masses, because of warm, moist air from the south overriding the cooler air.

A recent study(2) of the United States east of the Rocky Mountains gives an indication of the frequency of extended periods of light anticyclonic flow affecting northeastern Oklahoma. A 21-year period of record (1936-1956) was examined and light anticyclonic flows which persisted for periods of 4 days or more were tabulated. The 1:30 a.m. EST United States Weather Bureau Daily Surface Maps were used and only those areas where the geostrophic wind was less than approximately 15 knots were considered. Only 2 cases occurred in the Tulsa area during the period of record studied; each lasted for an average of 4 to 5 days. Thus, the topography and climatology of this region do not appear to favor conditions that are conducive to extended periods of high concentrations of pollutants.

III. TOPOGRAPHY AND CLIMATOLOGY OF THE GREATER TULSA AREA

A. TOPOGRAPHY

Tulsa is situated on the Arkansas River at an elevation of 600 to 800 feet msl. The river is oriented northwest-southeast through Oklahoma. Tulsa lies on a 90° bend in the river, which approaches the southwestern part of the city from just south of west, and leaves in a direction just east of south.

The terrain in and around the city consists mostly of rolling hills; however, in several localized areas just outside the city limits the terrain rises rather sharply to an elevation of 200-300 feet above the surrounding areas.

A range at approximately 950 ft. msl lies about 6 miles west of the central business district and curves northeastward. A lower range of hills, about 750-850 ft. msl, begins 11 miles northeast of the business district and extends eastward and southward to about 11 miles east of the business district.

B. CLIMATOLOGY

1. Winds

An examination of the Tulsa wind roses shows a decided skewness in the distribution of wind directions (Fig. 1, a-e). Southerly winds prevailed during all months of the year except for January, when north winds were experienced 1 percent more of the time than were south winds. Annually, south winds occurred about 22 percent of the time; east and west winds each occurred less than 2 percent of the time.

It is not likely that the river valley has much effect on the wind data presented. Any effects of wind-channelling caused by the slight river valley would most likely be experienced in or adjacent to this valley.

A tabulation was made of the frequency of occurrence of given wind directions for each hour of the day during the month of September (Fig. 3) to determine if any diurnal variations in wind direction could be found which could be attributed to the topography. September data were chosen because of the high frequency of occurrence of winds less than 8 mph and of opaque sky cover less than 0.3; these conditions occurred 47 and 71 percent of the time respectively, during the hours from 1:00 a.m. to 7:00 a.m. in September for the period of record used.(5) However, observations of all velocities for all hours were included in this tabulation.

The most noticeable diurnal variation occurs with south-southeast and south-southwest winds, the former of which is more predominant during the nighttime hours, and the latter through the daytime. These variations also show up in the plots of southeast and southwest winds, respectively.

Less noticeable is the diurnal variation of northwest, north-northwest and north winds (most frequent at night), and north-northeast, northeast, and east-northeast winds (more frequent, generally, during the day).

These variations are most likely due to the diurnal variations in the vertical transfer of momentum between the

lower atmospheric layers. During the daytime, when low-level turbulence is generally at its greatest, the transfer of momentum between air strata reaches its maximum; the surface wind direction and velocity then correspond more closely with the gradient wind (at approximately 1500 feet above the surface). At night, with less turbulence in the lower atmospheric layers, there is less downward momentum transfer from higher levels, and the wind velocity decreases near the surface. This decrease in speed is accompanied by a counterclockwise shift in the surface wind direction as a result of dynamic adjustments in the flow.

There is no evidence from this preliminary analysis to show that the diurnal variation in the winds at the Tulsa Airport could be attributed to topography, although a more detailed examination of the wind data might show a topographical effect on light winds at this location. There are, undoubtedly, such effects in other localized sections of the Tulsa area.

When low-level stability data become available from the present study being conducted in Tulsa, they can be compared with the following information on wind persistence to determine the relationships between these parameters.

A tabulation was made of various periods of wind persistence, using a 5-year period of record (1949-1953) of Tulsa wind data.(3) These periods of persistence were based on the continuous duration of hourly winds from a given direction, plus or minus 2 points of the 16-point compass. Thus, if during a 24-hour period the wind direction varied between south and west, the only direction with a 24-hour persistence for that period of record would be southwest; the persistences of the other counted directions (southeast clockwise through northwest) would vary between 1 and 23 hours, depending upon the chronological distribution of directions during the period.

The longest periods of persistence from each direction are plotted by month in the form of persistency wind roses (Fig. 4). The longest periods of persistence occurred in June from the south-southeast, south, and south-southwest. Each of these directions experienced a period of persistence of more than 10 days. In February, northerly and southerly winds persisted for approximately equal

intervals. January and March were the only months during which winds with a northerly component persisted for longer intervals than did those with a southerly component.

Table 2 shows the monthly distribution of speed persistencies for winds less than 8 mph. There were 5 cases of persistence greater than 24-hours duration in each of July and August, and 4 cases in October; these were the months of greatest frequency of the longer persistences during the 5-year period of record.(3)

The month of July experienced 3 periods of light winds persisting more than 36 hours; this appears to be the month of the greatest frequency of longer periods of persistency of low velocities. The greatest persistency of this speed classification occurred in October, and lasted for 46 hours.

It may be possible, upon completion of the data reduction of the present Tulsa air pollution survey, to relate wind persistence to air pollution. At present, it is merely assumed that wind speed is inversely related to pollutant concentrations, with 8 mph arbitrarily the critical wind speed between high and low concentrations at the surface.

2. Temperature and Relative Humidity

The temperature distribution at Tulsa is typical of that of a continental type climate at 36 degrees north latitude. Temperatures fall below freezing on an average of 73 days per year, and exceed 90°F on 72 days per year.(6) High summer temperatures are generally accompanied by low relative humidities.

The annual distribution of monthly temperatures, and of relative humidities, is shown in Fig. 5. The occurrence of relative humidities below 50 percent is greater during autumn and early spring than during winter and summer. The percentage frequency of occurrence of these low humidities varies from 13 percent in June and July to 33 percent in October and November.

Relative humidities of 70 percent and higher occur

more frequently in winter and summer (50 and 51 percent of the time, respectively) than in spring and autumn (44 and 40 percent, respectively).

3. Visibility

The size of condensation nuclei in the atmosphere is little affected by the moisture in the air as long as the relative humidity remains below roughly 70 percent. According to a study by H. Neuberger(10), at humidities above roughly 70 percent the nuclei increase in size to a point where the visibility is affected, if the majority of the aerosols present are hygroscopic in nature. Thus, visibility can be a function of relative humidity as well as of particle number.

Figure 7 shows the seasonal variability of visibility categories as related to wind direction.(8) The frequency of occurrence of visibility, in given categories for a given direction, is plotted as percent of total observations from that direction. Hence, from Fig. 7a, 23 percent of all observations of north winds were accompanied by visibilities of 6 miles or less. These figures contain all observations, regardless of relative humidity. A further breakdown was made, using only the observations when the humidity was 85 percent or greater; but because of the low frequency of occurrence of restricted visibilities in this humidity category, the results are not shown. However, these data are not at variance with the complete visibility data presented in Figs. 7 (a-d).

Even when using observations which include all humidities, some of the directions occurred so infrequently as to make the data questionable. An illustration of this is contained in Fig. 7c, showing that 20 percent of the observations with west winds were accompanied by visibilities of 6 miles or less; however, there were only 55 hourly observations with west winds during the summers of 1949 through 1953.

Generally speaking, for all wind directions, the greatest number of observations of visibility below 6 miles occurred in winter, followed in order by spring,

autumn, and summer. The increased particulate emissions from both local and distant sources in the autumn, winter, and spring due to cold season heating is the probable cause of this seasonal variation. The validity of this statement is based on the fact stated above, i.e., since the number of cases of low visibilities associated with humidities above 85 percent is small, the ratio of low visibilities as a result of hydrometeors to total cases of low visibilities may be considered insignificant. Dust, which is carried into the air from the drier regions to the west, may restrict the visibility at times, but this phenomenon occurs relatively infrequently.

4. Precipitation

Washout, the removal of material from the air due to capture by falling precipitation, may act to cleanse the lower portion of the atmosphere;(11) therefore, a brief discussion of precipitation and related factors is appropriate.

More than one-third of Tulsa's precipitation normally occurs during late spring and early summer (April, May, and June), with a secondary peak occurring in September, as shown in Fig. 2. These four months account for nearly 50 percent of the annual precipitation. The three winter months receive less than 15 percent of the annual total.

Also shown in Fig. 2 are the annual distributions of days with precipitation and days with thunderstorms. The number of days with precipitation is based on a 5-year period of record (1949-1954); the lowest frequency of such days occurs in the fall months, with a mean of 8 days per month. The noticeable drop in frequency in June in this figure becomes less apparent when longer periods of records are used. The number of days with thunderstorms is at a low during the months of November to January (1 day per month), and increases to a high of 10 days in June (19-year mean, 1936-1954).

5. Sky Cover

Solar and terrestrial radiation play an important role in determining low-level stability in the atmosphere. Sky cover plays an important role by interfering with the free transmission of the short- and long-wave radiation (solar and terrestrial, respectively) through our atmosphere.

Clear skies during the daytime permit rapid heating of the ground, producing low-level convective instability. At night, clear skies permit the ground and the lower levels of the atmosphere to cool rapidly by radiation and mixing, thus increasing low-level stability. These relationships are borne out in a study by Singer and Raynor(9), in which they relate lapse rates with cloud cover. Since there is a lack of low-level stability data from Tulsa at present, sky cover will be used here as an indication of stability.

Fogs are generally associated with stable, slow-moving air, and the presence of stratus clouds is also an indication of stable conditions. Stable rather than adiabatic lapse rates may prevail during conditions of fog or low-level stratus; therefore, observations of these hydrometeors should be omitted from the tabulations. However, in view of the fact that only 5 percent of the observations in a 5-year period of record showed ceilings within 1000 feet of the surface (such ceilings would include fog and stratus), it was considered unnecessary to eliminate such observations from existing tabulations.

The month to month variations of days with cloudy skies (0.8-1.0 sky cover) are rather uniform. The highest frequency occurs in January (over 50 percent of the days), and decreases more or less gradually to a low of about 30 percent in August, September, and October, followed by a rather sharp increase through the remainder of the year to January (Fig. 2). The mean monthly percentage of possible sunshine varies from 48 in January to 74 in August, with a mean annual value of 61 percent.

A further breakdown of special tabulations(7) was made, and is included here as Figure 6 in which percentage

frequencies of occurrence of total* and of opaque sky cover for "day" and "night" periods are shown. The hours of 12:00 noon to 3:00 p.m. were chosen to represent day, and 12:00 midnight to 3:00 a.m. to represent night.

The month of September experiences the greatest frequency of clear skies (0.0-0.2 sky cover) during both the day and night periods. Clear skies are reported during approximately 57 percent of the day hours, and 76 percent of the night hours. From these data it can be inferred that the maximum diurnal variations in low-level stability occur in September.

The above percentages are based on opaque sky cover, since total sky cover includes all clouds. Thin or wispy type clouds do not inhibit transmission of radiation to the extent that opaque clouds do; therefore, they do not have the resultant effect that opaque clouds have upon low-level stability.

IV. SUMMARY AND CONCLUSIONS

It would be extremely difficult to determine quantitatively the dispersion parameters in Tulsa, on the basis of existing meteorological data. However, adequate data of hourly surface wind direction and speed are available from one location. This type of data is especially valuable when the observations are taken concomitantly with wind measurements at higher levels above the ground, but may be used independently in making an estimate of dispersion.

Wind speeds in Tulsa are generally strong enough to induce mechanical turbulence; this turbulence creates a moderate to high rate of mixing in the lower layers of the atmosphere, and pollutants are readily dispersed.

The low frequency of occurrence of extended periods of low velocity winds in this area indicates there is little chance of extended periods of slow or non-moving

* Entered in Figure 6 for uses other than in this report.

air parcels. This is in agreement with the study of persistent light anticyclonic wind flows mentioned previously(2). The topography is such that even during these infrequent episodes, it is unlikely that a given parcel of air will remain in the area for extended periods.

As in most other sections of the United States, such conditions are more likely to exist here in the autumn than in any other season.

The lowest frequencies of winds occur from the east and west directions. This fact should be taken into consideration in city planning, since wind direction is the factor which determines the trajectory of air-borne pollutants.

In general, the climate and topography of this area favor dispersion and the rapid exodus of pollutants.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the assistance of Mr. F. Pooler, Jr. for his numerous suggestions and critical review of the report, and Mr. E. W. Oscarson for taking charge of the final stages of preparation.

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5. Frequency of Wind Speed by Wind Direction (by month and hour). USWB. (Unpublished) (1957).

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8. Frequency of Visibility by Relative Humidity by Wind Direction, Tulsa, Oklahoma. USWB. (Unpublished) (1957).

9. Irving A. Singer and Gilbert S. Raynor, Analysis of Meteorological Tower Data, April 1950 - March 1952. Brookhaven National Laboratory, Upton, New York. (Unpublished).

10. H. Neuberger, Introduction to Physical Meteorology. Pennsylvania State College, (1951). p. 11.

11. Meteorology and Atomic Energy. USWB for AEC. U. S. Government Printing Office, Washington, D. C. (1955). pp. 88-98.

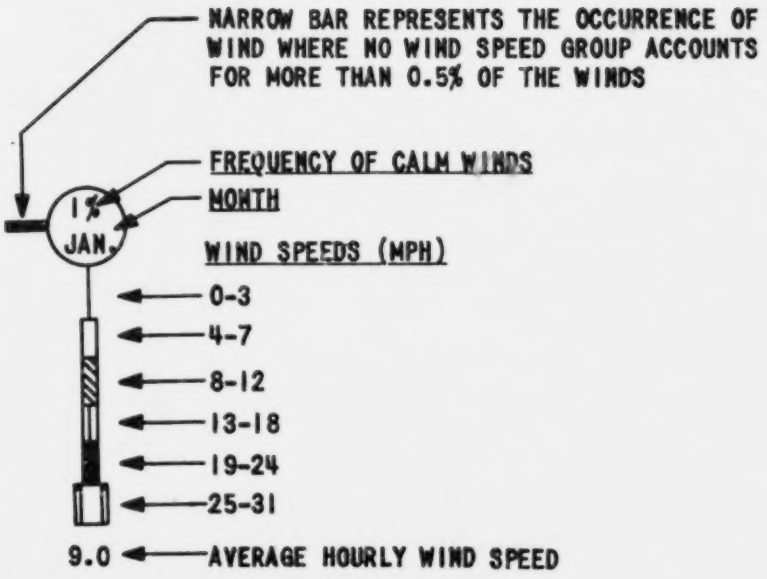
Table 1. NUMBER OF DAYS PER MONTH WITH ANY SURFACE CYCLONE CENTER WITHIN THE SOUTHERN GREAT PLAINS AREA BOUNDED BY 30° AND 40° N LATITUDE AND BY 90° AND 105° W LONGITUDE.

Monthly Means of Data from January 1899 to December 1938(4).

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
3.7	4.0	5.6	5.7	5.4	3.5	2.0	2.0	2.1	2.8	3.5	4.1

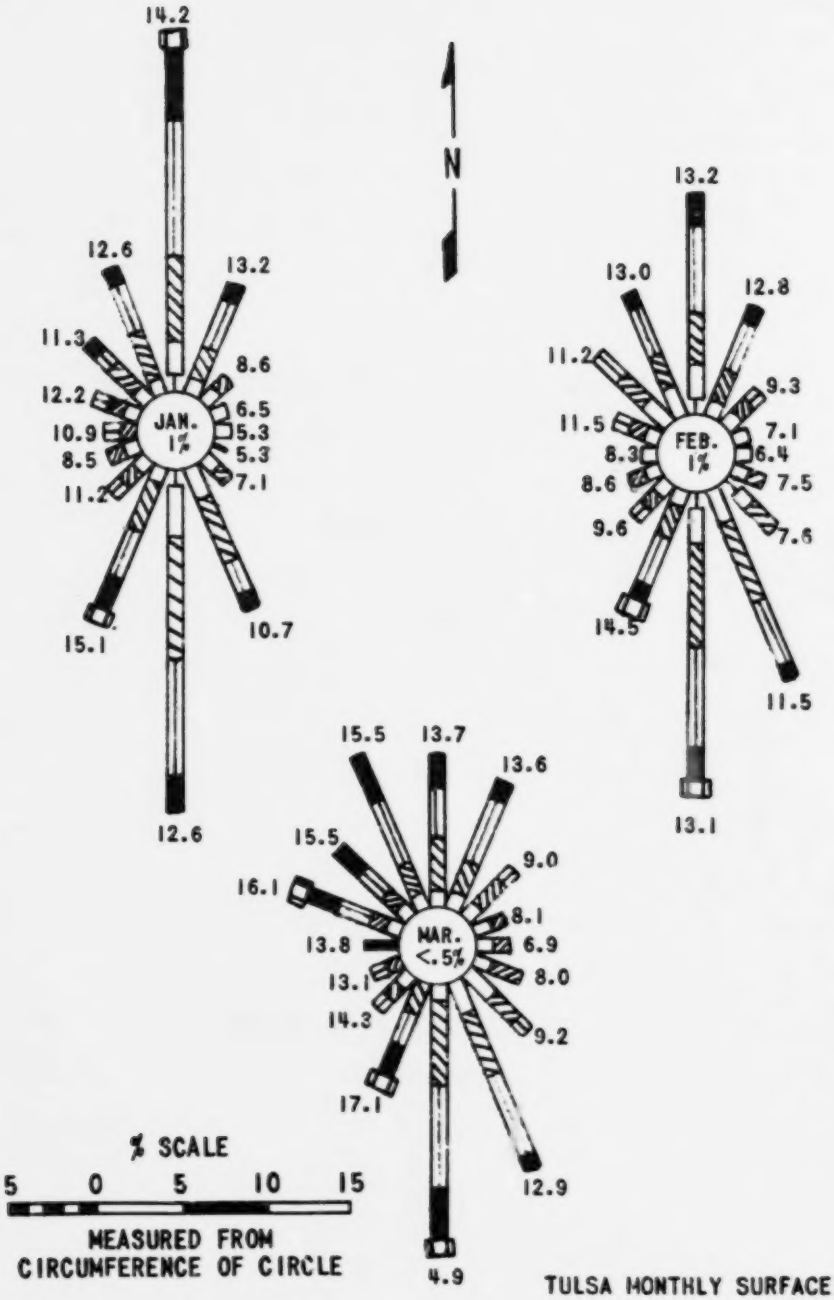
Table 2. FIVE-YEAR SUMMARY OF FREQUENCY OF OCCURRENCE OF GIVEN PERIODS WITH CONSECUTIVE HOURLY WIND SPEEDS $\geq$ 7 MPH AT TULSA (3).

Length of period, hours	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	TOTAL
24-29	1	2	0	1	2	1	1	2	2	1	3	2	18
30-35	0	0	0	0	0	1	1	2	0	2	0	0	6
36-47	1	1	1	0	0	1	3	1	0	1	0	0	9
$\geq$ 48	0	0	0	0	0	0	0	0	0	0	0	0	0
Totals	2	3	1	1	2	3	5	5	2	4	3	2	33



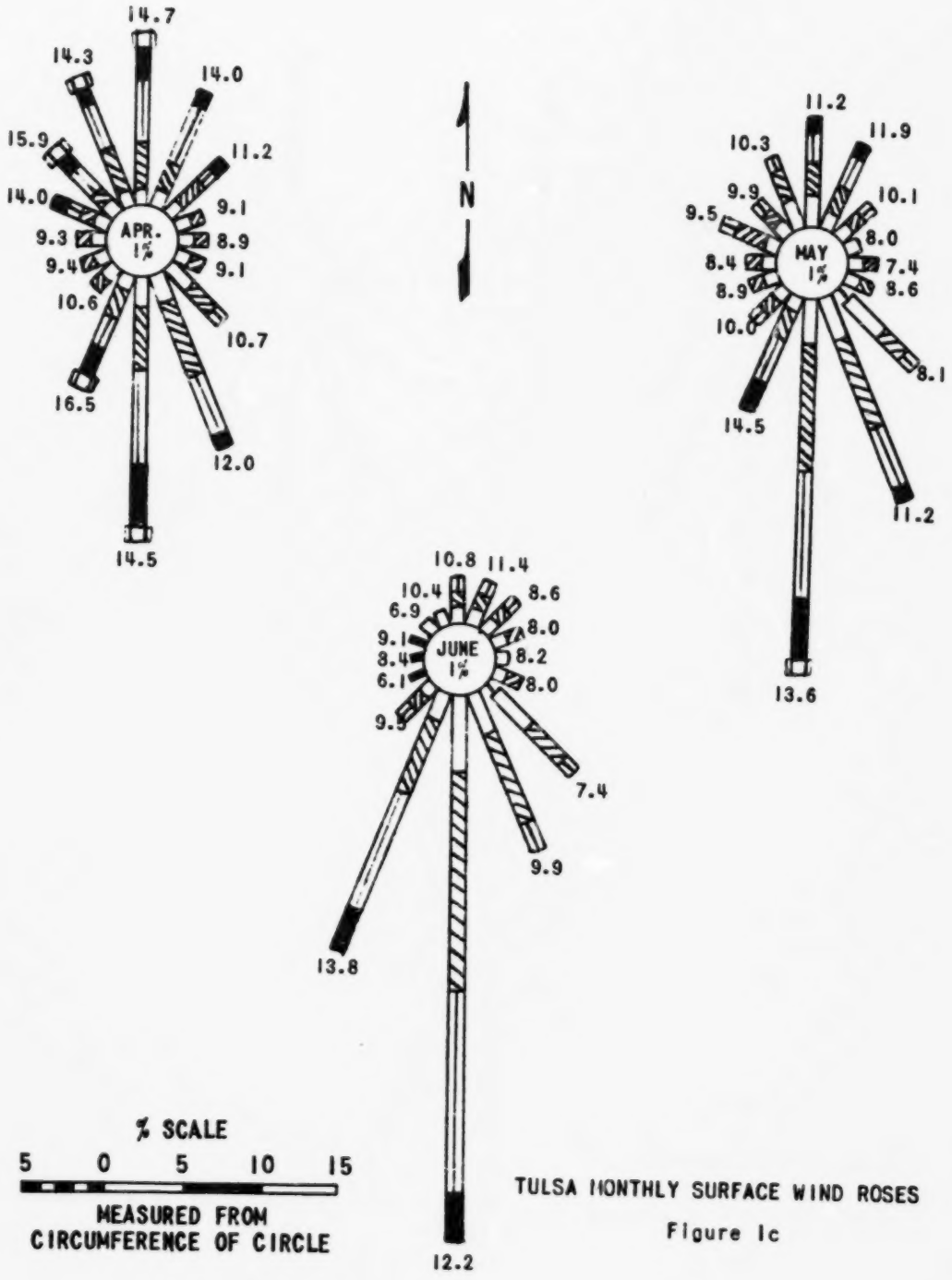
KEY TO SURFACE WIND ROSES

Figure 1a



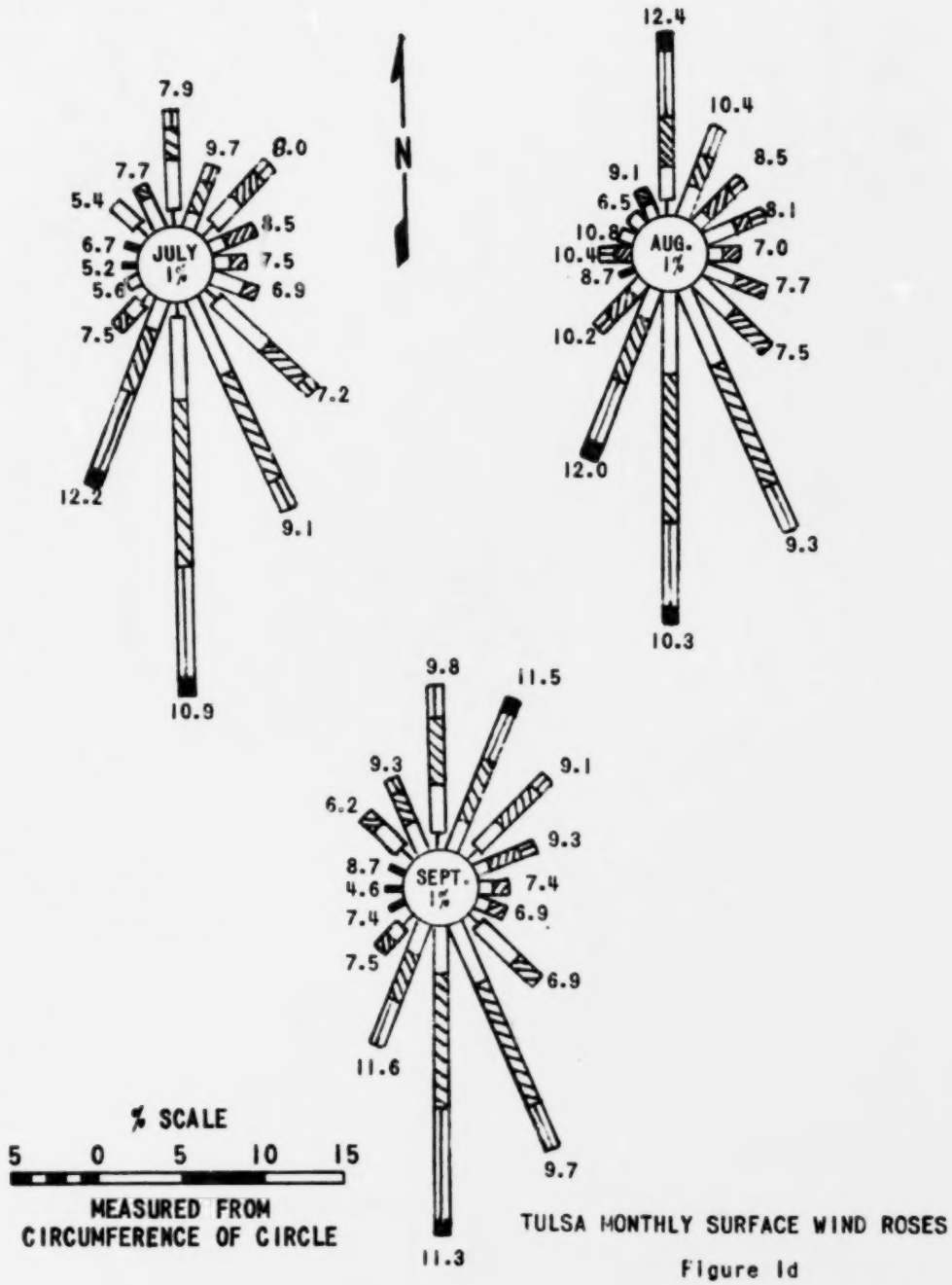
TULSA MONTHLY SURFACE WIND ROSES

Figure 1b



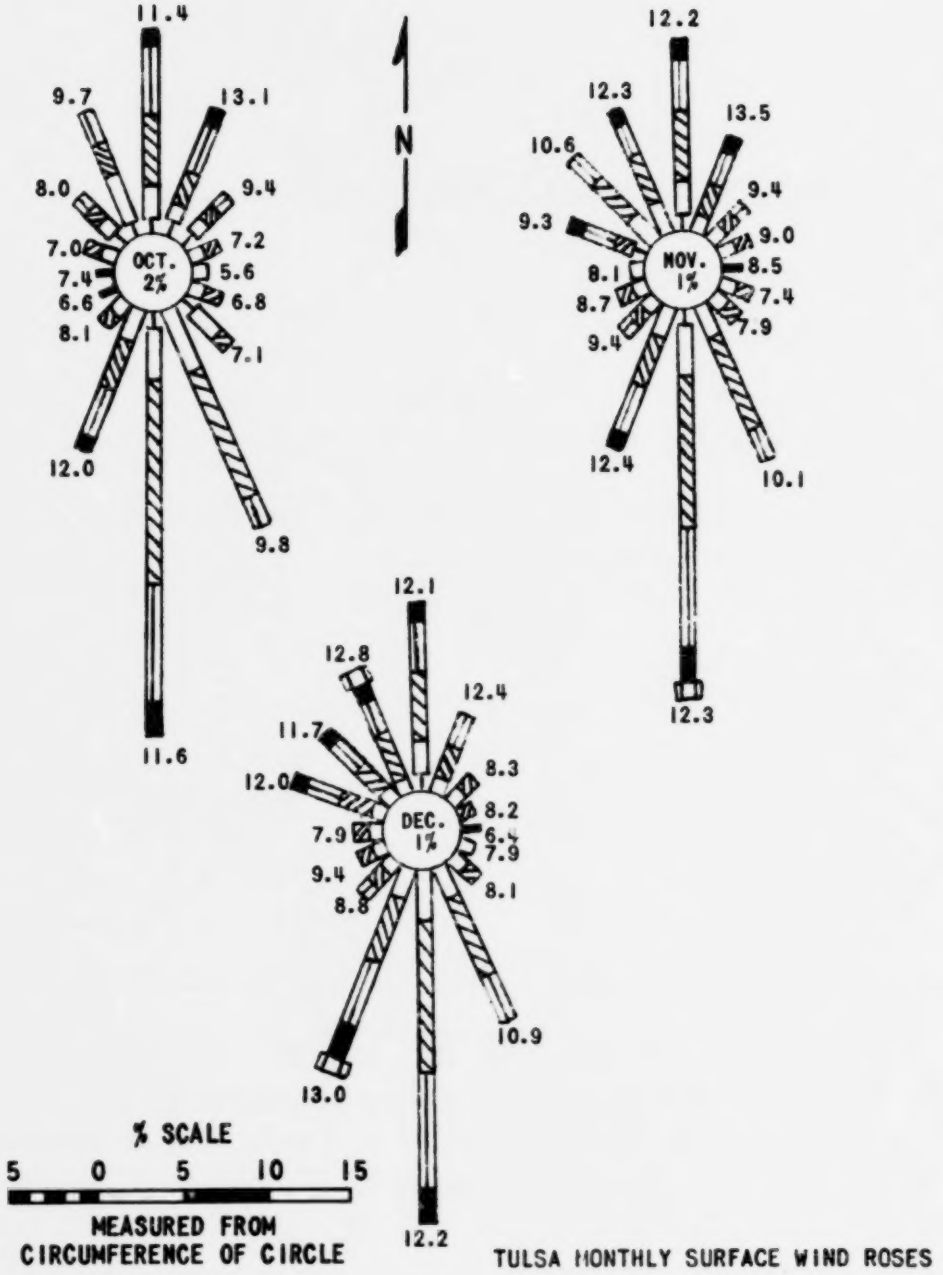
TULSA MONTHLY SURFACE WIND ROSES

Figure 1c



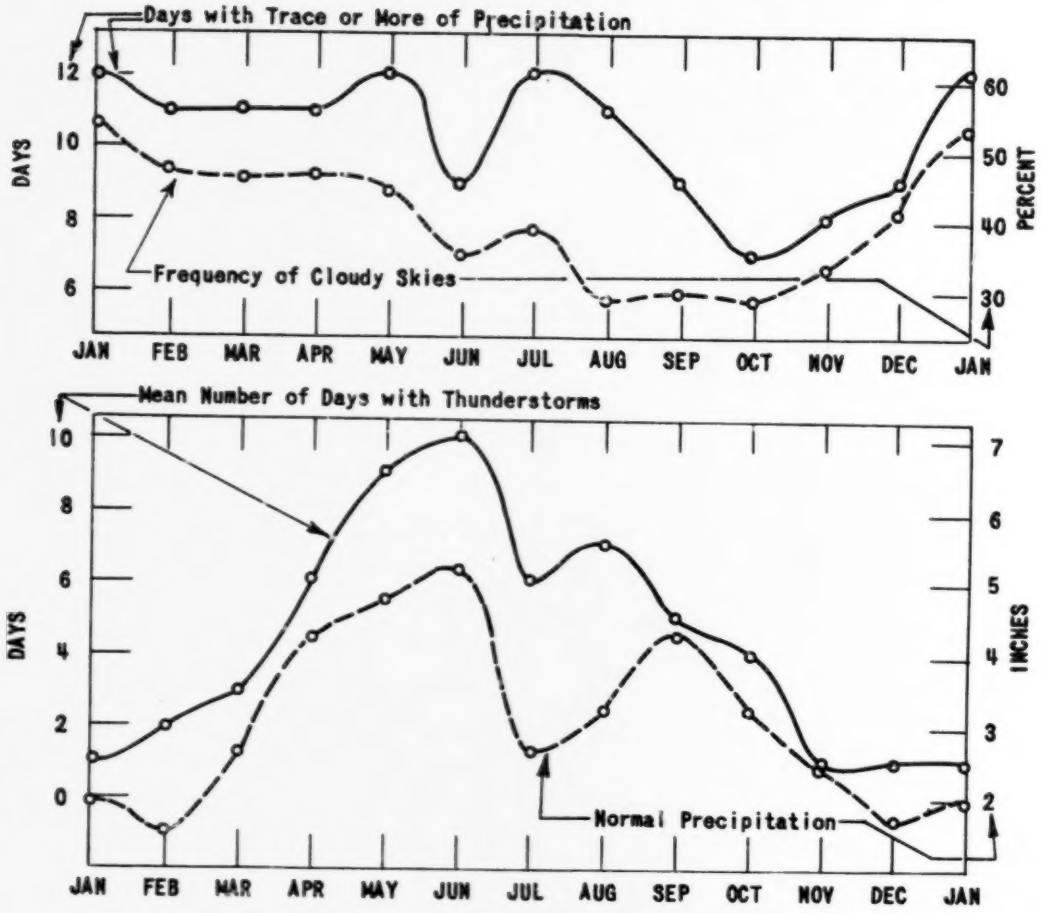
TULSA MONTHLY SURFACE WIND ROSES

Figure Id



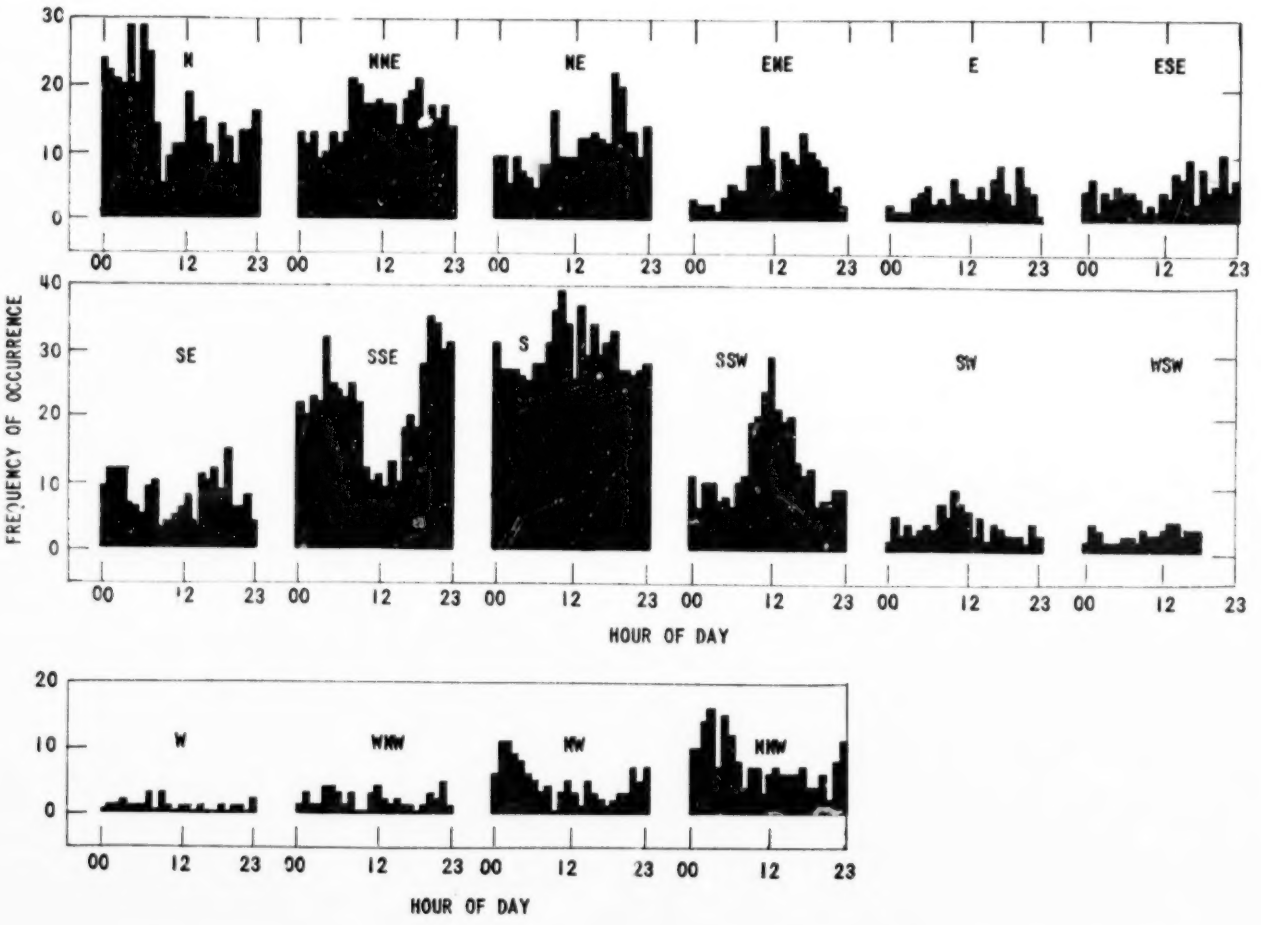
TULSA MONTHLY SURFACE WIND ROSES

Figure 1e


Days with Trace or More of Precipitation
DAYS
PERCENT
Frequency of Cloudy Skies
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC JAN
Mean Number of Days with Thunderstorms
DAYS
INCHES
Normal Precipitation
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC JAN

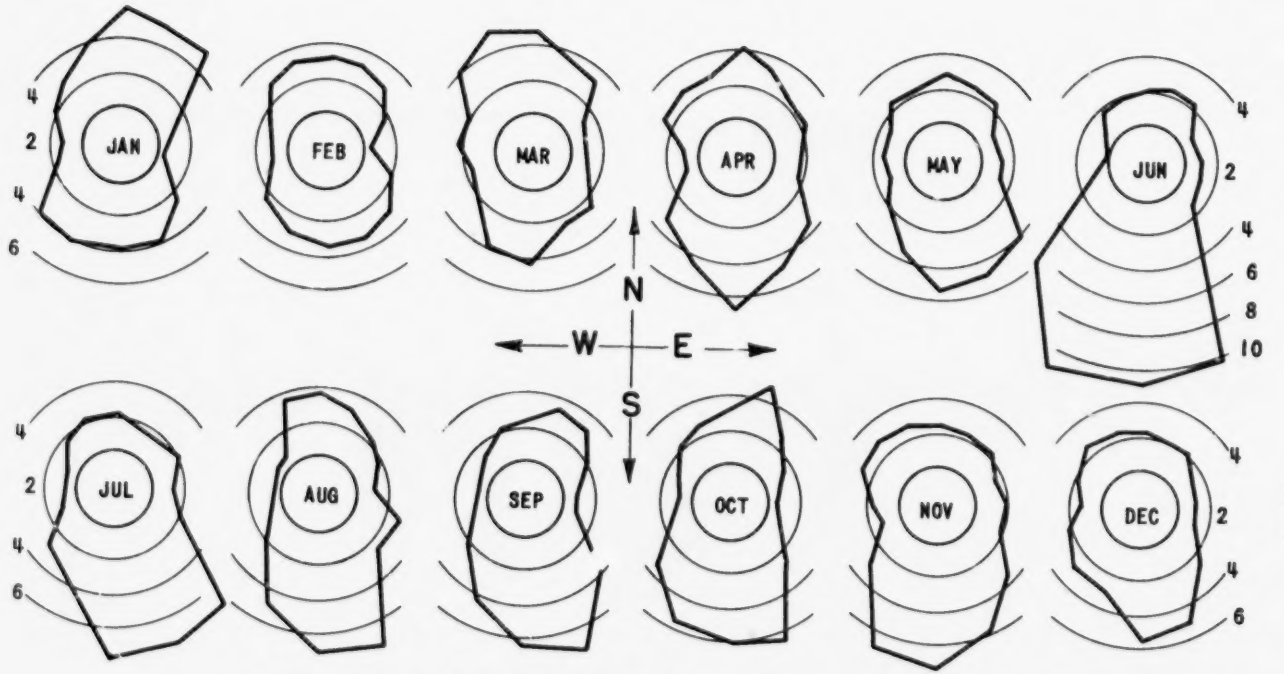
SELECTED METEOROLOGICAL STATISTICS ASSOCIATED WITH STABILITY AND WASH-OUT (Refs. 1,7, 6 and 1, Top to Bottom)

Figure 2

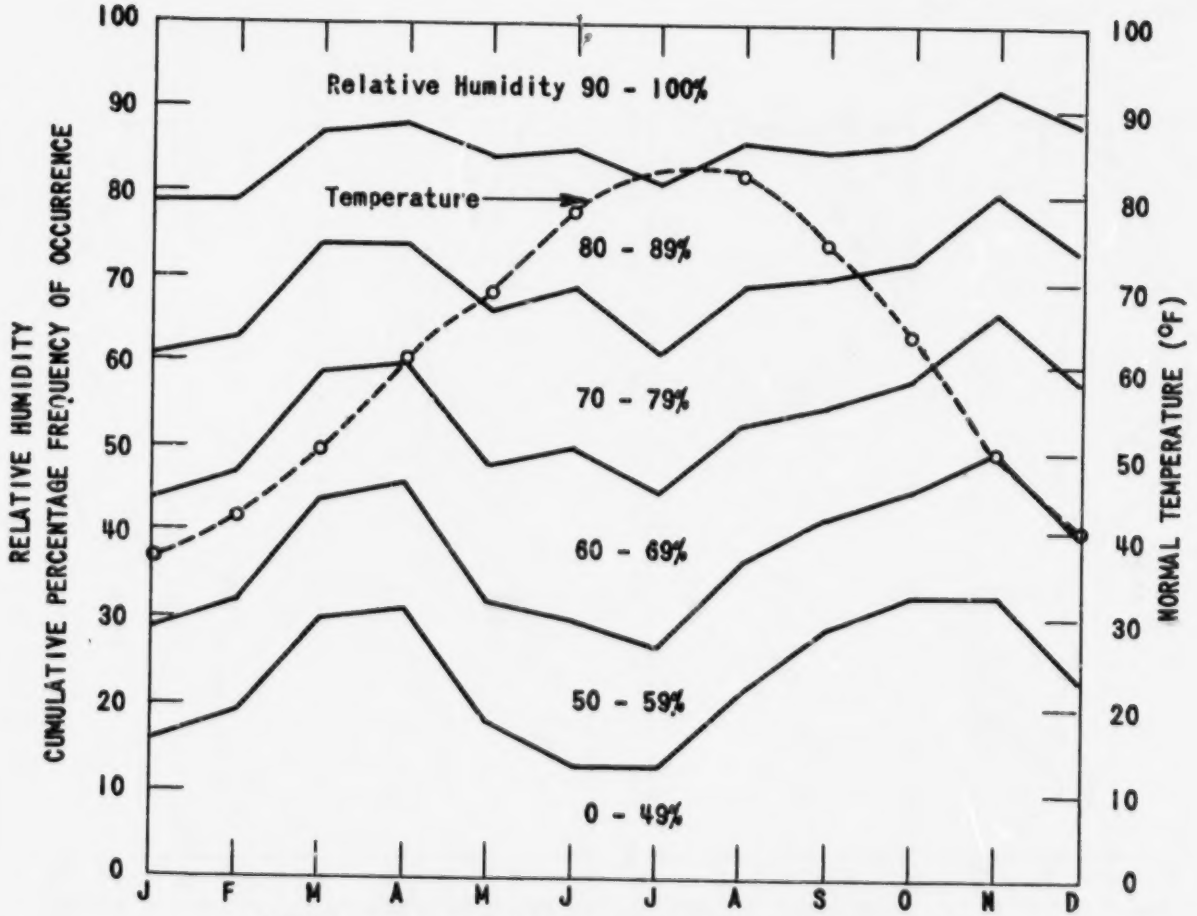


TULSA HOURLY FREQUENCIES OF WIND DIRECTIONS (September, 5-yr. Total 1949-1953[5])

Figure 3

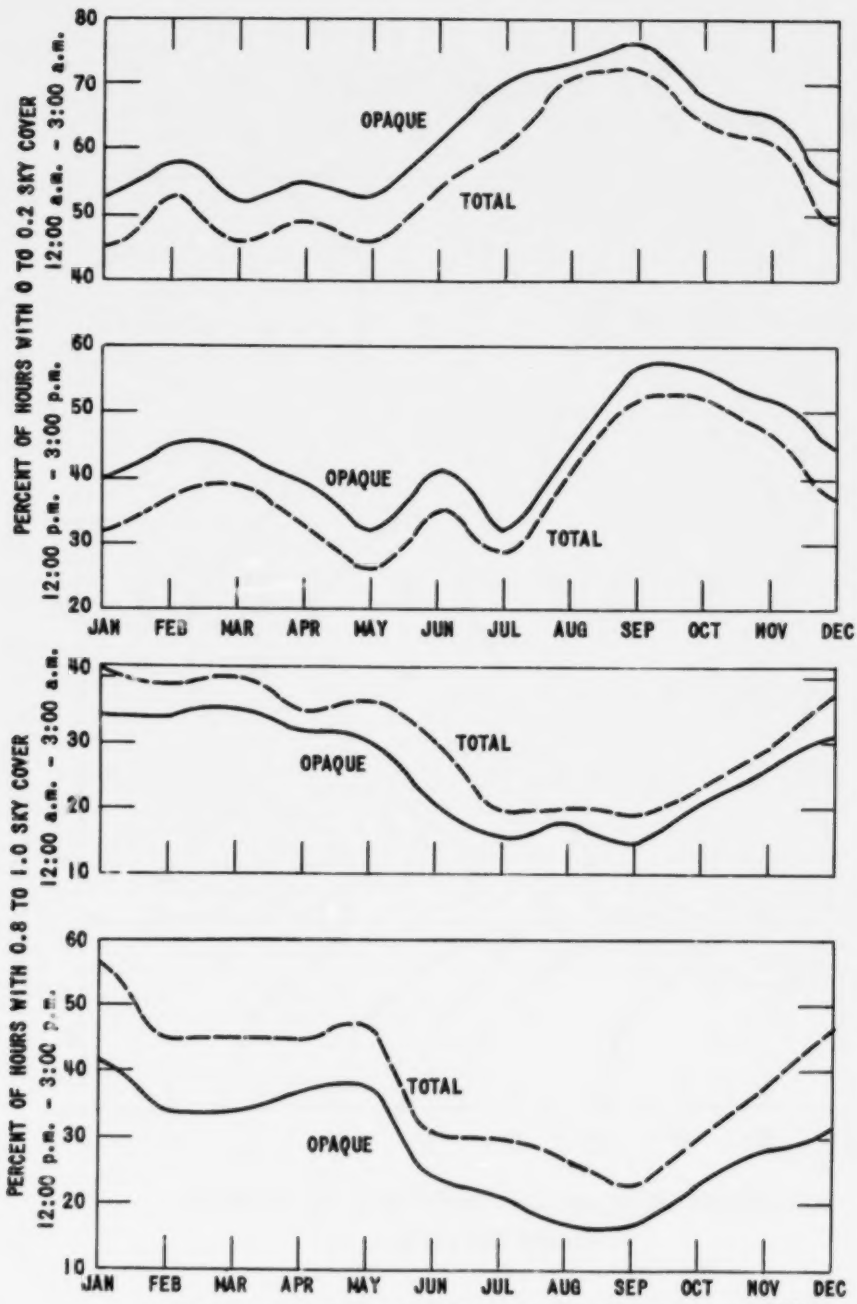


PERSISTENCY WIND ROSES, 1/49 THROUGH 12/53
GREATEST PERIOD OF PERSISTENCE, TULSA(3)
Figure 4



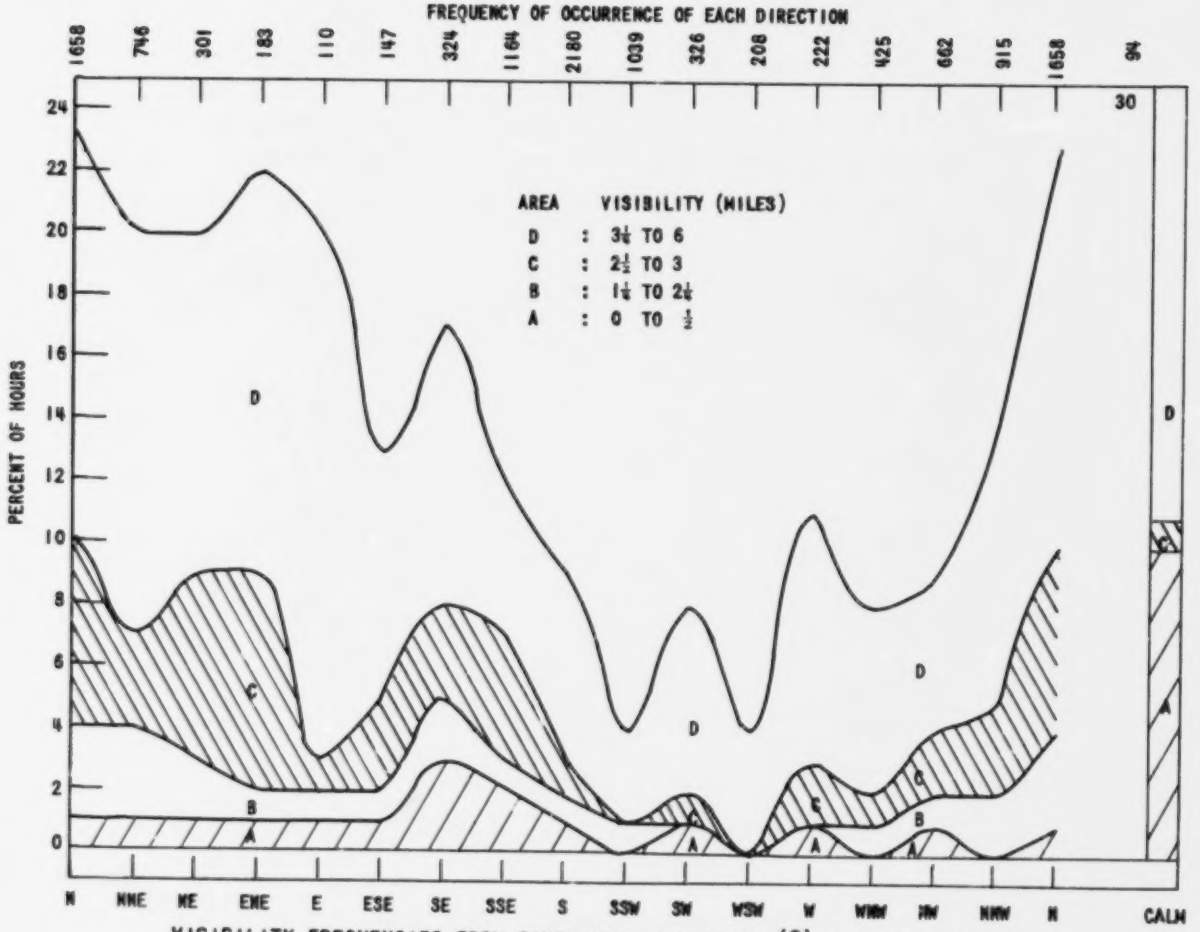
CUMULATIVE FREQUENCIES OF RELATIVE HUMIDITY CLASSES(1) AND NORMAL TEMPERATURES(6) TULSA

Figure 5



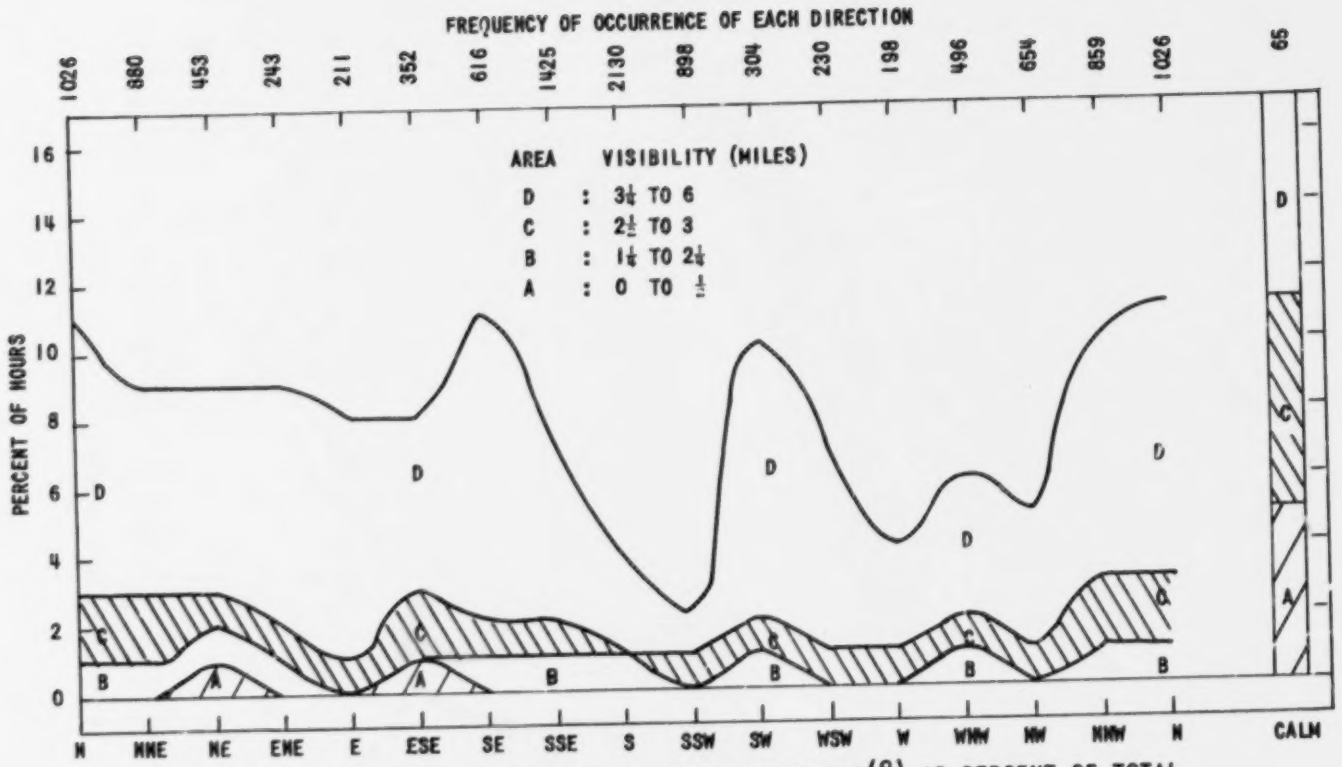
DIURNAL VARIATION OF TOTAL AND OPAQUE SKY COVER(7)

Figure 8


FREQUENCY OF OCCURRENCE OF EACH DIRECTION
1658 746 301 183 110 147 324 1164 2180 1039 326 208 222 425 662 915 1658 94
30
PERCENT OF HOURS
24 22 20 18 16 14 12 10 8 6 4 2 0
AREA VISIBILITY (MILES)
D : 3¼ TO 6
C : 2½ TO 3
B : 1¼ TO 2¼
A : 0 TO ½
N NNE NE ENE E ESE SE SSE S SSW SW WSW W WNW NW NNW N CALM

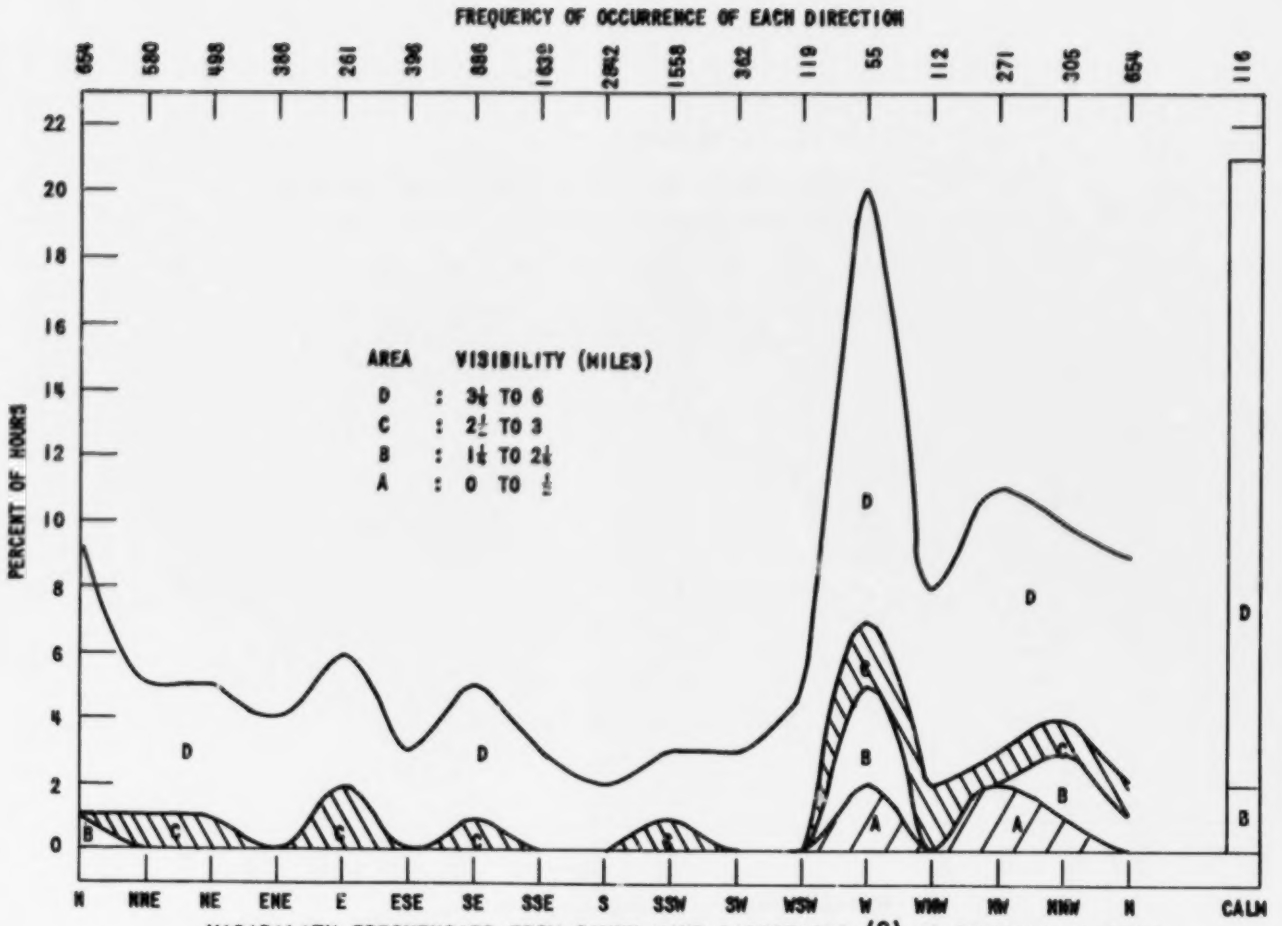
VISIBILITY FREQUENCIES FROM GIVEN WIND DIRECTIONS(8) AS PERCENT OF TOTAL OBSERVATIONS OF EACH DIRECTION (Winter: Dec., Jan., Feb.)

Figure 7a


FREQUENCY OF OCCURRENCE OF EACH DIRECTION
1026 880 453 243 211 352 616 1425 2130 898 304 230 198 496 654 859 1026 65
AREA VISIBILITY (MILES)
D : 3¼ TO 6
C : 2½ TO 3
B : 1¼ TO 2¼
A : 0 TO ½
PERCENT OF HOURS
0 2 4 6 8 10 12 14 16
N NNE NE ENE E ESE SE SSE S SSW SW WSW W WNW NW NNW N CALM

VISIBILITY FREQUENCIES FROM GIVEN WIND DIRECTIONS(8) AS PERCENT OF TOTAL OBSERVATIONS OF EACH DIRECTION (Spring: March, April, May)

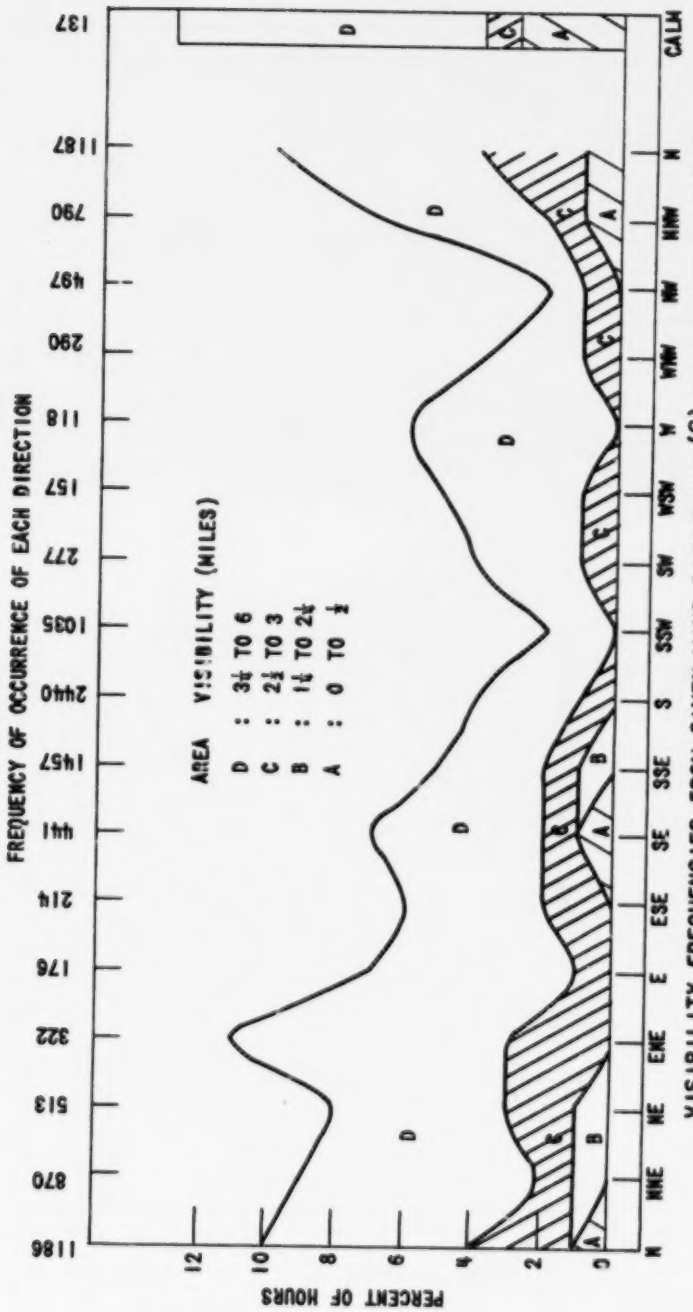
Figure 7b


FREQUENCY OF OCCURRENCE OF EACH DIRECTION
654 580 498 386 261 396 886 1638 2852 1558 362 119 55 112 271 305 654 116
PERCENT OF HOURS
22 20 18 16 14 12 10 8 6 4 2 0
AREA VISIBILITY (MILES)
D : 3½ TO 6
C : 2½ TO 3
B : 1¼ TO 2½
A : 0 TO ¾
N NNE NE ENE E ESE SE SSE S SSW SW WSW W WNW NW NNW N CALM

VISIBILITY FREQUENCIES FROM GIVEN WIND DIRECTIONS (8) AS PERCENT OF TOTAL OBSERVATIONS OF EACH DIRECTION (Summer: June, July, Aug.)

Figure 7c

12



VISIBILITY FREQUENCIES FROM GIVEN WIND DIRECTIONS(8) AS PERCENT OF TOTAL OBSERVATIONS OF EACH DIRECTION (Autumn: Sept., Oct., Nov.)

Figure 7d